Planning and Optimization

E13. Merge-and-Shrink: Pruning and Usage in Practise

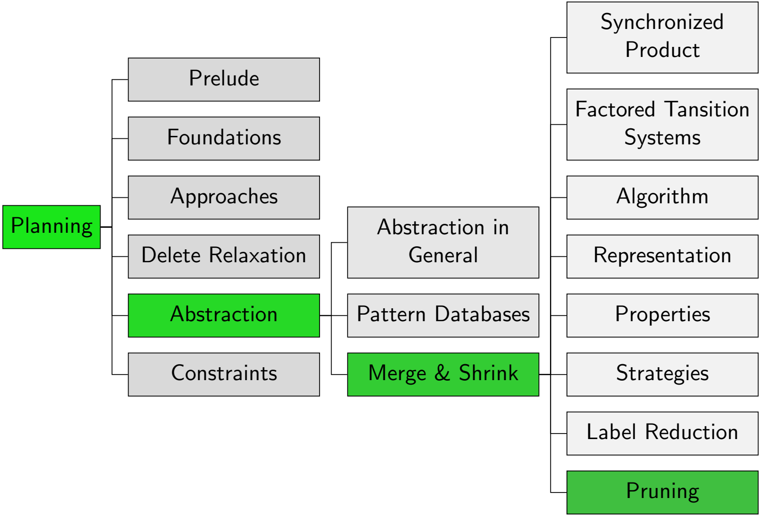
Malte Helmert and Gabriele Röger

Universität Basel

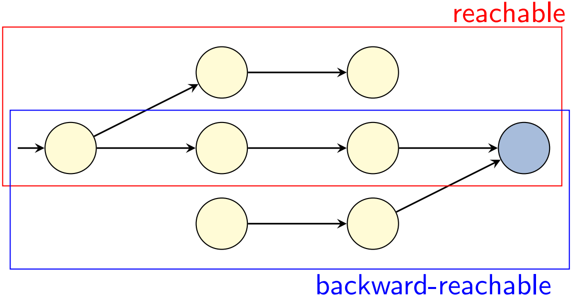
November 25, 2024

E13.1 Pruning

Content of the Course



Alive States



- state s is reachable if we can reach it from the initial state
- state s is backward-reachable if we can reach the goal from s
- state s is alive if it is reachable and backward-reachable
  $\rightarrow$ only alive states can be traversed by a solution
- a state s is dead if it is not alive.

Pruning States (1)

- If in a factor, state s is dead/not backward-reachable then all states that "cover" s in a synchronized product are dead/not backward-reachable in the synchronized product.
- Removing such states and all adjacent transitions in a factor does not remove any solutions from the synchronized product.
- This pruning leads to states in the original state space for which the merge-and-shrink abstraction does not define an abstract state.
  $\rightarrow$ use heuristic estimate ∞

Pruning States (2)

- Keeping exactly all backward-reachable states we still obtain safe, consistent, goal-aware and admissible (with conservative transformations) or perfect heuristics (with exact transformations).
- Pruning unreachable, backward-reachable states can render the heuristic unsafe because pruned states lead to infinite estimates.
- However, all reachable states in the original state space will have admissible estimates, so we can use the heuristic like an admissible one in a forward state-space search such as A^*(but not in other contexts like such as orbit search).
  We usually prune all dead states to keep the factors small.

E13.2 Merge-and-Shrink in Practise

Merge-and-Shrink

- Merge-and-Shrink is a general framework.
- The full framework also covers label reduction and pruning.
- For all transformations, we need to select a strategy.
  merge, shrink, label reduction, pruning strategy
- The general strategy orchestrates the tranformations.
  How can this look like in practise?

Merge-and-Shrink in Fast Downward

Input: Factored transition system F, merge strategy MS, shrink strategy SS, prune strategy PS, label reduction strategy LRS, size limit $N \in \mathbb{N}$.
Output: Trans. system $\mathcal{T}$ and mapping σ from states of $\bigotimes F$ to states of $\mathcal{T}$.

$\triangleright$ *Copy input factored transition system, compute Σ to represent the identity state mapping on $\bigotimes F'$, set λ to the identity label mapping.*
$\langle F', \Sigma, \lambda \rangle \leftarrow \langle F, \{\pi_{\mathcal{T}} \mid \mathcal{T} \in F'\}, \mathbf{id} \rangle$

for $\mathcal{T} \in F$ **do**
  $\triangleright$ *Prune atomic factor $\mathcal{T}$ with PS.*
  $\langle F', \Sigma, \lambda \rangle \leftarrow \textsc{ComposeTransformation}(\textsc{Prune}(F', \mathcal{T}))$
end for
...

Merge-and-Shrink in Fast Downward (cont'd)

while $|F'| > 1$ **do**

$\triangleright$ *With MS, select two factors from F to be merged in this iteration.*

$\mathcal{T}_1, \mathcal{T}_2, \leftarrow \textsc{Select}(F')$

$\triangleright$ *With LRS, apply a label reduction to F'.*

$\langle F', \Sigma, \lambda\rangle \leftarrow \textsc{ComposeTransformation}(\textsc{LabelReduction}(F'))$

$\triangleright$ *With SS, shrink $\mathcal{T}_1$ and $\mathcal{T}_2$ so that the size of their product respects N.*

$\langle F', \Sigma, \lambda\rangle \leftarrow \textsc{ComposeTransformation}(\textsc{Shrink}(F', \mathcal{T}_1, \mathcal{T}_2, N))$

$\triangleright$ *With LRS, apply a label reduction to F'.*

$\langle F', \Sigma, \lambda\rangle \leftarrow \textsc{ComposeTransformation}(\textsc{LabelReduction}(F'))$

$\triangleright$ *Apply the merge transformation.*

$\langle F', \Sigma, \lambda\rangle \leftarrow \textsc{ComposeTransformation}(\textsc{Merge}(F', \mathcal{T}_1, \mathcal{T}_2))$

$\triangleright$ *With PS, prune the product factor $\mathcal{T}^{\otimes}$ of $\mathcal{T}_1$ and $\mathcal{T}_2$.*

$\langle F', \Sigma, \lambda\rangle \leftarrow \textsc{ComposeTransformation}(\textsc{Prune}(F', \mathcal{T}^{\otimes}))$

end while

return single elements $\mathcal{T} \in F'$ and $\sigma \in \Sigma$

Stopping Early

- Merge-and-shrink has significant precomputation time before we can start the search.
- We typically stop the algorithm after a preset time (e.g. half of the time that is overall available).
- The factored transition system then still contains several factors. Each of them induces an individual heuristic.
- We can combine them by taking the maximum or use a generalization of operator cost partitioning (cf. Ch. F7/8) to labels to obtain better estimates.
- Cost partitioning benefits from additional snapshots of factors from several iterations of merge-and-shrink.

State of the art: snapshots and saturated cost partitioning (Ch.F8)

E13.3 Literature

Literature (1)

References on merge-and-shrink abstractions:

Klaus Dräger, Bernd Finkbeiner and Andreas Podelski.
Directed Model Checking with Distance-Preserving Abstractions.
Proc. SPIN 2006, pp. 19–34, 2006.
Introduces merge-and-shrink abstractions (for model checking) and DFP merging strategy.

Malte Helmert, Patrik Haslum and Jörg Hoffmann.
Flexible Abstraction Heuristics for Optimal Sequential Planning.
Proc. ICAPS 2007, pp. 176–183, 2007.
Introduces merge-and-shrink abstractions for planning.

Literature (2)

- Raz Nissim, Jörg Hoffmann and Malte Helmert.
  Computing Perfect Heuristics in Polynomial Time:
  On Bisimulation and Merge-and-Shrink Abstractions
  in Optimal Planning.
  Proc. IJCAI 2011, pp. 1983–1990, 2011.
  Introduces bisimulation-based shrinking.

- Malte Helmert, Patrik Haslum, Jörg Hoffmann
  and Raz Nissim.
  Merge-and-Shrink Abstraction: A Method
  for Generating Lower Bounds in Factored State Spaces.
  Journal of the ACM 61 (3), pp. 16:1–63, 2014.
  Detailed journal version of the previous two publications.

Literature (3)

Silvan Sievers, Martin Wehrle and Malte Helmert.
Generalized Label Reduction for Merge-and-Shrink Heuristics.
Proc. AAAI 2014, pp. 2358–2366, 2014.
Introduces modern version of label reduction.
(There was a more complicated version before.)

Gaojian Fan, Martin Müller and Robert Holte.
Non-linear merging strategies for merge-and-shrink
based on variable interactions.
Proc. SoCS 2014, pp. 53–61, 2014.
Introduces UMC and MIASM merging strategies

Literature (4)

Malte Helmert, Gabriele Röger and Silvan Sievers.
On the Expressive Power of Non-Linear Merge-and-Shrink Representations.
Proc. ICAPS 2015, pp. 106–114, 2015.
Shows that linear merging can require a super-polynomial blow-up in representation size.

Silvan Sievers and Malte Helmert.
Merge-and-Shrink: A Compositional Theory of Transformations of Factored Transition Systems.
JAIR 71, pp. 781–883, 2021.
Detailed theoretical analysis of task transformations as sequence of transformations.

Literature (5)

Silvan Sievers, Florian Pommerening , Thomas Keller and Malte Helmert.
Cost-Partitioned Merge-and-Shrink Heuristics for Optimal Classical Planning.
Proc. IJCAI 2020, pp. 4152–4160, 2020.
Extends saturated cost partitioning to merge-and-shrink.

E13.4 Summary

Summary

- Pruning is a transformation that is used to keep the size of the factors small. It depends on the intended application how aggressive the pruning can be.
- In practise, it is beneficial to set a time limit for merge-and-shrink. The factors can be considered as individual admissible heuristics.